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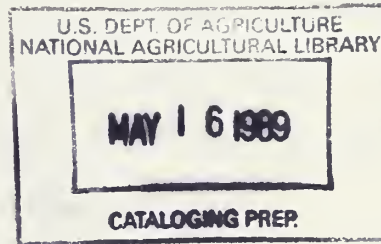
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INDUSTRIAL PRODUCTION AND QUALITY OF WHOLE CARCASS
BEEF ROLLS USED IN THE WHOLESOMENESS TESTING
OF RADAPPERTIZED BEEF

by

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Presented at
The First International Congress
on
Engineering and Food
Boston, Massachusetts
August 9-13, 1976

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In the United States and other countries, ionizing radiation has been defined as a "food additive" so as to control its use as a food preservative; thus, it is banned unless approval for its use is granted by the appropriate regulating agencies (the US Food and Drug Administration [FDA] and the US Department of Agriculture in the United States). The petition requesting approval must include experimental evidence to indicate the wholesomeness and safety of the food.

In 1970 the US Army Medical Department, in cooperation with the FDA, prepared a research protocol to demonstrate the wholesomeness and safety of radappertized beef. This study involved chemical analysis, mutagenic, teratogenic, and other studies and feeding of the radappertized beef and appropriate controls to dogs, rats, and mice with subsequent examination of the animals. The details and pertinent aspects of the protocol have been discussed by Raica and Baker, 1973 and Johnson et al., 1974.

To conduct the wholesomeness studies as outlined in the protocol, large quantities of beef were required. This paper details the industrial production of the whole beef carcass processed in the form of beef rolls, subdivided into four groups; nonirradiated control group and three groups further processed by different preservation methods. It also deals with acceptance and storage stability of the products after the processing.

EXPERIMENTAL: The research protocol requires the use of enzyme-inactivated beef (EI) subdivided into four groups:

Frozen Control (FC) beef - packaged in metal cans and stored frozen without further processing.

Thermally Processed (TP) beef - packaged in metal cans, preserved by high temperature (117°C) processing and stored without refrigeration.

Gamma Ray Irradiated (GAM) beef - packaged in metal cans; preserved by gamma-ray irradiation and stored without refrigeration.

Electron Irradiated (ELE) beef - packaged in flexible pouches; preserved by electron irradiation and stored without refrigeration.

The research and development of process criteria for manufacturing the EI beef rolls are discussed by Wierbicki et al., 1976. During the period January 1971 through October 1973, a total of 188,471 kg was procured from a large midwest meat packer. The products were manufactured under contract to US Army Natick Research and Development Command (NARADCOM) in seven productions (Table 1). A brief summary of the process follows:

Raw Material: Whole carcasses of deboned, chilled, USDA inspected beef were used as the basic material.

The carcasses were trimmed to a fat content of less than 20%. For the first 4 productions, the beef was cut by hand into pieces ranging from 50 g to 700 g. It was observed that there was a large variation in fat (both in chunk size and in total fat) in the containers, which was due to the large variation in piece size without any restriction in piece thickness. For the last three productions, the beef was sliced by machine* into 2.5-cm-thick slices. A representative sample (approximately 25 kg) from each lot of beef (a lot being one day's production) was taken for analytical purposes. This sample was twice ground using a 0.6-cm plate, packed in cans, and frozen. Part was shipped to the feeding site, and the balance to NARADCOM.

Additives: Salt (NaCl) (0.75%) and sodium tripolyphosphate (TPP)(0.375%) were added to the raw meat to prevent excessive losses of natural juices during enzyme inactivation and to improve flavor and acceptance (Shults et al., 1972). All of the additives in the amount specified are within the USDA regulations as applied to beef (USDA, 1976). Crushed ice (3.0%) was also added to facilitate dissolution and diffusion of the additives in the meat. The meat and the additives, in 625-kg batches were thoroughly mixed for approximately 20 minutes in a vacuum mixer (175 \pm 5 mm Hg pressure) and then stuffed into the appropriate size regenerated cellulose casings. The beef for packaging in cans (FC, TP, and GAM groups) was stuffed into No. 6½ casings to yield a roll with 102-cm diameter. The beef for packaging in pouches (ELE group) was stuffed into No. 11 casings, which were then pressed into 9.0 X 12.5 X 814 cm wire cages to give the beef a shape that could easily be packaged into flexible pouches after cutting into 13 mm thick slices.

*Holac, Robt. Reiser & Co., Boston, MA

Enzyme Inactivation: The beef rolls were enzyme-inactivated in a cookhouse so that the rolls reached a center temperature of at least 68°C and not more than 74°C and a yield of not more than 85% based on the weight of the raw meat. After enzyme inactivation, the rolls were spray washed, chilled, and stored under refrigeration until packaged.

Packaging and packing: Details for the development and FDA approval of the cans and flexible packaging material, and procedures for packaging the beef are discussed by Killoran et al., 1976a, 1976b. The procedure was essentially as follows:

FC Beef: 1.25 kg per 404 X 700 can, packed 12 cans per case, stored frozen.

TP Beef: 368 g per 404 X 202 can, thermally processed, packed 48 cans per case, stored without refrigeration.

GAM Beef: 1.25 kg per 404 X 700 can, packed 12 cans per case, stored frozen until radappertized.

ELE Beef: 9.0 X 12.5 X 1.3 cm slice per pouch, 2 pouches per pouch box, 8 pouch boxes per irradiation box, 8 irradiation boxes per case, stored frozen until radappertized.

For packaging, the casings were removed from the rolls and the beef cut into appropriate size pieces. For the FC and GAM groups, the pieces were cut approximately 15 cm long, packed into cans (404 X 700), weight adjusted to 1250 gm \pm 10 gm with small pieces of beef. The cans were closed under 175 \pm 5 mm Hg pressure, stored overnight under refrigeration, rechecked for internal can pressure, and frozen for shipment.

For the TP group, the beef was cut into 5-cm pieces, packed into 404 X 202 cans, and adjusted to 370 g \pm 5 gm. The cans were closed under

175 ± 5 mm Hg pressure, refrigerated overnight to stabilize to a constant temperature (2° to 3°C), and then thermally processed to $F_0 = 5.8$ (Cohen, 1974). After processing, the cans were stored without refrigeration.

For the ELE beef, the rolls were cut into 1.3-cm thick slices weighing approximately 115 g. The slices were packaged, one slice per pouch, into 10.4×17.9 -cm pouches. The pouches were closed under 105 ± 5 mm Hg. pressure and stored refrigerated overnight. After inspections for vacuum, integrity, and other factors, the pouches were packed into pouch boxes, irradiation boxes, and shipping cases, then frozen for shipment.

A "go-no-go" dosimeter (Holm and Jarrett, 1965) was attached to each GAM can and to each ELE pouch and pouch box.

The FC and TP beef with exception of samples needed at NARADCOM, were shipped directly to the animal feeding site. The GAM and ELE beef were shipped frozen to NARADCOM for radappertization.

Radappertization: The frozen GAM and ELE beef were further chilled to $-40^{\circ} \pm 5^{\circ}\text{C}$ prior to radappertization. They were given an irradiation dose of 47 to 71 kJ/kg (4.7 to 7.1 Mrad). Details of the dosimetry and irradiation are discussed by Jarrett and Halliday, 1976; MacDonald, 1976; and Rees and Caspersen, 1976. The use of this dose as the radappertizing 12D dose for beef is discussed by Anellis and Rowley, 1976.

Inspection: After irradiation and thawing, all cans and containers were inspected for container integrity and internal pressure. Any container which showed any defect (dents, wrinkled seams, can with more than 250 mm

internal pressure, pouches with loss of vacuum, etc.) were discarded.

The acceptable products (except for samples needed at NARADCOM) were shipped without refrigeration to animal feeding sites.

Evaluation at NARADCOM: Some samples from all 7 productions (both raw and EI) were analyzed for volatile radiolytic products (Merritt, 1976). Other samples were evaluated for proximate analysis, certain dynamic chemical factors, and acceptance. They were evaluated shortly after irradiation (within 30 days) and after 3, 6, 9, 12, and 15 months' storage at room temperature.

Representative samples of all groups of beef (raw and EI) were evaluated for moisture (H_2O), protein, fat, ash, salt ($NaCl$), phosphorus (P), and acidity (pH), using standard techniques (A.O.A.C., 1975). The EI samples were also periodically evaluated for nonprotein nitrogen (NPN) (Jacobs, 1951), free fatty acids (FFA), and peroxide values (PV) (Military Specification, MIL-C-4338C 1969), and malonaldehyde (TBA) (Tarladgis et al., 1960). The head space gases were analyzed for oxygen (O_2), nitrogen (N_2), carbon dioxide (CO_2), hydrogen (H_2), methane (CH_4), and carbon monoxide (CO) (Stark, 1976).

The meat producer also supplied this laboratory with the results of his analysis of the EI beef.

All irradiated samples were subjected to a microbiological examination prior to evaluation by the panelists (Heiligman, 1965). The sensory evaluations included discoloration, off-odor, irradiation flavor, off-flavor, mushiness, and friability by an 8-member technological panel using a 9-point intensity scale (Fig. 1) and for preference by an 8-member technological panel and a 32-member consumer panel using the 9-point hedonic scale (Fig. 2) of Peryam and Pilgrim, 1957. Means and standard deviations were

calculated for all factors investigated. Analysis of variance was also calculated to determine differences among the four groups of the beef.

RESULTS AND DISCUSSION

Chemical Analyses. The quality of the raw beef used in manufacturing the EI beef rolls was quite uniform. A summary of the proximate analysis of all lots of the raw beef is shown in Table 2. The only significant variability was in the fat content as the fat in the FC group was significantly greater than the fat in the other groups. This variability was probably caused by sampling problems due to the small sample size and the variability in the piece size. Analyses of the EI beef tend to substantiate this view as the contractor found the fat content in the ELE group significantly different from the fat content of the other group (Table 3) and NARADCOM found the fat content of the TP group (Table 4) different from the other groups.

The proximate analyses of the EI beef as determined by the contractor (Table 3) and by NARADCOM (Table 4) are in close agreement. The results show that the irradiation, thermal processing or storage had no effect on the protein, ash, salt and phosphorus content and probably none on the moisture and fat. There are statistical differences in the fat content, which, in turn, affect the moisture content. These differences, as previously mentioned, were caused by sampling problems and the variability in piece size of beef used for the beef roll manufacturing.

The effects of the irradiation, thermal processing and storage on the dynamic factors (pH, NPN, FFA, TBA and PV) are shown in Table 5. Neither the irradiation nor storage had an effect on the pH or NPN content in any

group, and this shows the enzyme inactivation, at least for proteolytic enzymes, was adequate.

Both the irradiation and thermal processing caused a small increase in free fatty acids (FFA); however, the thermal processing had more effect than the irradiation processing. Time in storage did not affect the FFA values in the FC and TP groups; but there was a small, but statistically significant, increase with time in the FFA in both irradiated groups. This increase could be caused by lipolytic enzymes. Similar results have been observed in other laboratories (Newar, 1976).

All TBA values were very low and no sensory rancidity was noted in any samples. There was a statistical difference in the initial TBA value in the TP group when compared to the other three groups and in both the TP and FC groups, the TBA values remained constant in storage. (No explanation as to why the TBA values in the 12-month period were statistically different from the other values as all values are very low.) There was a statistically significant decrease in the TBA values in both irradiated groups with the sharpest reduction occurring during the first 3 months of storage. These changes, although statistically significant, are of no practical importance since the initial values and those after storage are all very low and below the level for detection of rancidity by sensory evaluation (Watts, 1962; Sato et al., 1973).

All peroxide values (PV) were low. No differences in the PV determination were noted in the initial evaluation between the four groups. Also, storage seemed to have no effect on peroxide values as no difference due to time in storage was noted in the PVs in the two irradiated groups during the 15-month storage. No explanation can be offered concerning the high PVs noted in the 9-month TP samples and the 6, 9, and 12-month FC samples,

and if these values are eliminated from the statistical analysis, time in storage had no effect on the peroxide value in any group.

Head-space gas analyses. At the beginning of this study and during the early withdrawal, attempts were made to analyze the head-space gases in samples from all four groups. Since the TP samples were packaged in small cans, there was so little gas in the containers, attempts to analyze these were discontinued. Due to the small samples size (110 \pm 5g) the amount of gas in the head-space of the ELE group was small and attempts to analyze these were discontinued also. Samples from the FC and GAM groups were evaluated throughout the entire study (see Table 6). Due to problems in obtaining the head-space gas samples from the individual containers and the inability to do replicate analysis on the same sample, the range of the values for each of the constituents was large (note the large standard deviations). Time in storage seemed to have no effect but the irradiation had a marked effect. The irradiation caused the production of large quantities of hydrogen, some carbon dioxide and small, but detectable, quantities of methane and carbon monoxide. The radiolytic production of these gases, which account for almost half of the gas in the head-space of the irradiated samples, caused some loss in vacuum, and, in turn, a decrease in the percentage of nitrogen. Methane (less than 1%) was found in all of the irradiated samples, and carbon monoxide (less than 0.5%) in only a few. The techniques used in the analyses were designed to detect gases only if they occurred in levels of above 0.3 to 0.4%. The radiation destroys most of the oxygen as shown by lower amounts of O₂ in the GAM samples in comparison with the O₂ in the FC samples. These overall results are consistent with results obtained by Pratt et al., 1967; however, percentages differ due to differences in the food composition.

Acceptance Testing

Results of the technical and consumer panels on the effects of the various processing treatments and storage on the sensory and preference scores of the four groups of beef are shown in Tables 7 and 8 and graphically in Figures 3 to 10. These data indicate that storage had little if any effect on any of the acceptance factors studied. Irradiation and thermal processing did cause a slight discoloration when compared to enzyme inactivated beef stored frozen under vacuum. No difference in off-odor scores were detected between the FC and TP samples or between the GAM and ELE samples; however, the scores for the irradiated groups (GAM and ELE) were slightly higher than scores for the beef thermally processed (TP) or stored frozen (FC). Irradiation flavor was detected in samples from both irradiated groups, but the intensity was low. This was also noted by Merritt, et al. 1975. No differences in off-flavor scores were noted due to the preservation process, and again these scores for all samples were low. Both irradiation and thermal processing caused changes in texture; mushiness scores for the TP, GAM and ELE group were similar but slightly higher than the scores for the FC group; and, friability scores were similar for the two irradiated groups but lower than for TP group and slightly higher than for FC group.

All samples were scored in the acceptable range for preference by both the technical and the consumer panels. The scores were lower than are normally to be expected for beef. This was due to the type of product that was evaluated which was sliced beef roll prepared from whole carcass beef.

This product was not the same type as beef products that are normally served (roasts and steaks from special cuts). The radappertized beef products prepared for human consumption scored high in the acceptable range (Wierbicki et al., 1975, 1976). The technical panels scored both irradiated products the same as the thermally processed product but slightly lower than the frozen control. However, the consumer panel scored the GAM and ELE the same as the frozen control but slightly lower than the thermally processed samples.

SUMMARY AND CONCLUSIONS

Large quantities (188,471 kg) of enzyme-inactivated beef containing sodium chloride (0.75%) and sodium tripolyphosphate (0.375%) were produced in seven productions by a large industrial meat company for use in the wholesomeness testing of radappertized beef. Each production was divided into four approximately equal groups and was preserved by thermal processing, gamma ray irradiation, electron irradiation and freezing (in vacuum-sealed cans). Samples from all productions were studied over a 15-month storage period to determine the effects of the preservation method and time in storage on a variety of factors. The thermally processed, gamma-ray irradiated and electron irradiated samples of beef were stored at ambient (approx. 21°C), whereas the frozen samples were stored at -29°C. The following observations were made:

1. The beef used in the manufacturing of the seven productions of enzyme-inactivated beef was relatively uniform.
2. The overall composition of the enzyme-inactivated beef in the four groups was similar except for the variations in the fat content. The variability in

the fat content was due to sampling problems and to the variability in the lean-fat composition of the piece sizes of the raw meat used in making the meat rolls.

3. Neither the processing nor time in storage affected the "proximate" analysis of the beef.

4. The heating to inactivate proteolytic enzymes was adequate, as neither the processing treatment nor time in storage caused any change in pH or NPN content of the samples.

5. Both processing treatment and time in storage may have had a small effect on some of the lipid constituents. Irradiation and thermal processing caused an increase in the FFA, and time and storage caused a small, but significant, increase in the FFA in the irradiated groups. All TBA values were very low, but the initial TBA values in the TP beef was statistically lower than the others. The TBA values in both irradiated groups decreased while in storage. All PV were low and similar at the start of the study. The PV in both irradiated groups remained constant during the 15-month storage period.

6. The irradiation had a marked effect on the composition of the headspace gases in the cans. It caused the production of large quantities of H_2 , and CO_2 and detectable quantities of CH_4 and CO. The irradiation also caused a reduction in oxygen. Although the percentage of N_2 is much lower in the irradiated samples than in the frozen samples, the difference is due to the dilution of the N_2 by the radiolytic production of H_2 .

7. All samples scored in the acceptable range for preference throughout the study. The irradiated samples were scored slightly lower than either of

the conventionally preserved samples by both the technical and the consumer panels. The irradiation, as expected, caused a slight increase in off-odors. The irradiation also caused a slight increase in mushiness and friability when compared to the frozen controls, but caused less damage than thermal processing for these characteristics.

This paper reports research undertaken at the US Army Natick Research and Development Command and has been assigned No. TP-1912 in the series of papers approved for publication. The findings in this report are not to be construed as an official Department of the Army position.

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Table 1. Commercial production of enzyme inactivated beef

Production Number	Contract Number	Date	Quantity kg.
1A	DAAG-17-71-C-0061	8 JAN 71	907
1B	DAAG-17-71-C-0083	4 MAR 71	10433
1C	DAAG-17-71-C-0096	9 APR 71	11340
1B2 *	DAAG-17-71-C-0716	14 MAY 71	2495
2A	DAAG-17-72-C-0083	21 DEC 71	11340
2B	DAAG-17-72-C-0096	27 JAN 72	11340
3	DAAG-17-72-C-0111	3 APR 72	22680
4	DAAG-17-73-C-0070	12 DEC 72	22680
5	DAAG-17-73-C-0120	1 MAR 73	34020
6	DAAG-17-74-C-0010	9 AUG 73	34020
7	DAAG-17-74-C-0143	23 MAY 74	27216

* to replace TP in 1B which was overprocessed



Table 2. Summary of proximate analyses of raw beef used in producing enzyme inactivated beef rolls

Group	H ₂ O			Protein			Fat			Ash			NaCl			pH		
	(%)			(%)			(%)			(%)			(%)					
n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd	
FC	18	66.6	1.1	18	18.7	0.6	18	14.1*	2.5	18	0.89	0.04	12	0.7	0.09	18	5.6	0.2
TP	18	67.0	1.4	18	18.8	0.6	18	12.7	1.7	18	0.89	0.03	12	0.7	0.07	18	5.6	0.2
GAM	19	67.0	1.5	19	19.0	1.0	19	12.1	2.0	19	0.89	0.03	12	0.7	0.08	19	5.5	0.2
ELE	20	67.3	2.1	20	19.0	1.0	20	12.5	2.8	20	0.89	0.05	14	0.8	0.08	20	5.5	0.2

* sig:95% level



Table 3. Summary of proximate analyses of enzyme-inactivated beer
(Data from contractor)

Group	H ₂ O			Protein			Fat			NaCl			P		
	n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd
FC	13	61.1	0.3	13	21.7	0.8	13	15.9	3.7	13	0.96	0.08	12	430	21
TP	12	61.3	2.3	12	21.9	1.0	12	15.1	2.7	12	0.98	0.06	10	422	17
GAM	14	60.9	3.0	14	22.3	1.6	14	14.7	1.4	14	0.97	0.10	12	354	13
ELF	15	61.6	1.3	15	22.6	1.2	15	13.9*	2.3	15	0.93	0.06	13	336	12

*sig: 95% level



Table 4. Summary of proximate analyses of enzyme-inactivated beef.

Group	Initial			3 months			6 months			9 months			12 months			15 months			Overall			
	n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd	
H ₂ O (%)	FC	19	62.0	3.1	4	59.6	2.4	6	60.2	15	5	59.6	3.0	4	58.6	2.5	7	59.2	3.0	45	60.6	3.0
	TP	19	63.8	3.0	4	63.9	2.8	6	61.5	2.9	5	64.4	1.3	5	56.5	13.7	7	61.7	2.5	46	62.4	5.1
	GAM	19	60.7	3.4	4	60.1	1.0	6	61.0	2.6	5	60.6	2.0	5	58.3	1.9	7	58.0	2.0	46	60.0	2.9
Prote. (%)	FC	19	62.3	2.4	4	60.6	3.9	6	22.0	1.5	5	59.9	3.5	5	59.5	2.4	7	60.3	1.2	46	61.2	2.6
	TP	19	21.7	1.4	4	21.6	0.7	6	23.0	2.3	5	21.9	2.6	4	21.1	1.4	7	22.0	0.4	45	21.9	1.6
	GAM	19	22.5	1.4	4	22.0	0.5	6	23.0	1.2	5	21.2	0.8	5	22.3	1.0	7	21.6	1.5	46	22.2	1.3
Fat (%)	FC	19	21.3	1.7	4	22.9	0.7	6	22.1	1.0	5	22.1	1.3	5	22.2	1.7	7	21.8	0.6	46	21.8	1.4
	TP	19	22.4	1.5	4	21.8	1.6	6	22.4	0.8	5	22.1	0.9	5	21.8	1.3	7	22.0	0.4	46	22.2	1.2
	GAM	19	13.8	3.9	4	16.1	3.2	6	14.9	1.9	5	16.1	3.6	4	18.0	2.9	7	16.4	1.4	45	15.2	3.4
Ash (%)	FC	19	11.2	3.1	4	11.2	3.2	6	13.4	2.1	5	12.3	1.4	5	12.9	2.7	7	14.6	4.0	46	12.3	3.1
	TP	19	15.3	4.6	4	14.1	1.9	6	14.8	3.2	5	14.8	2.8	5	17.4	2.8	7	18.1	1.7	46	15.8	3.7
	GAM	19	12.7	3.6	4	15.2	4.3	6	13.6	2.4	5	15.2	5.4	5	16.6	3.4	7	15.7	1.7	46	14.1	3.7
Moist. (%)	FC	18	2.0	0.1	4	2.1	0.2	6	2.0	0.1	5	2.0	0.2	4	2.0	0.2	7	2.1	0.1	44	2.0	0.1
	TP	18	2.0	0.1	4	2.2	0.1	6	2.1	0.1	5	2.0	0.1	5	2.1	0.2	7	2.1	0.1	45	2.1	0.1
	GAM	18	2.1	0.1	4	2.0	0.2	6	2.0	0.1	5	2.1	0.1	5	2.0	0.1	7	2.1	0.1	45	2.1	0.1
pH	FC	18	2.1	0.1	4	2.0	0.1	6	2.1	0.1	5	2.0	0.1	5	2.1	0.1	7	2.1	0.1	45	2.1	0.1
	TP	13	0.9	0.1	4	0.9	0.1	6	0.9	0.1	5	1.0	0.2	4	1.0	0.1	7	1.0	0.1	38	1.0	0.1
	GAM	13	0.1	0.1	4	1.0	0.1	6	0.9	0.2	5	1.0	0.1	5	1.0	0.1	7	1.0	0.2	40	1.0	0.1
pH	FC	13	0.1	0.1	4	0.9	0.1	6	0.9	0.1	5	1.0	0.1	5	1.0	0.1	7	1.0	0.1	40	1.0	0.1
	TP	13	0.1	0.1	4	0.9	0.1	6	0.9	0.1	5	1.0	0.1	5	1.0	0.1	7	1.0	0.1	40	1.0	0.1
	GAM	13	0.1	0.1	4	0.9	0.1	6	0.9	0.1	5	1.0	0.1	5	1.0	0.1	7	1.0	0.1	40	1.0	0.1
pH	FC	13	0.1	0.1	4	0.9	0.1	6	1.0	0.1	5	1.0	0.1	5	1.0	0.1	7	1.0	0.1	40	1.0	0.1
	TP	18	272	16	4	288	28	6	280	13	5	275	21	4	274	14	7	285	16	44	277	17
	GAM	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
pH	FC	18	272	16	4	288	28	6	280	13	5	275	21	4	274	14	7	285	16	44	277	17
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	279	13	7	282	15	45	277	15
pH	FC	18	285	17	4	284	23	6	283	10	5	272	10	5	277	9	7	286	17	45	283	16
	TP	18	278	12	4	302	17	6	277	36	5	273	11	5	283	7	7	292	19	45	282	19
	GAM	18	272	14	4	278	18	6	280	17	5	281	18	5	2							





Table 6 Summary of head-space gas analysis in cans of frozen control (FC) and gamma-ray irradiated (GAM) enzyme inactivated beef.

Gas	Group	Time in storage														
		Initial			3 Month			6 Month			9 Month			12 Month		
		n	AVG	sd	n	AVG	sd	n	AVG	sd	n	AVG	sd	n	AVG	sd
O ₂ (%)	FC	15	1.2	0.6	4	2.4	2.3	4	4.7	4.2	5	4.7	4.1	6	2.3	1.8
	GAM	18	0.9	0.3	4	1.2	0.6	3	1.5	0.6	5	0.7	0.1	6	0.9	0.4
N ₂ (%)	FC	14	82.9	8.2	4	83.7	2.4	4	84.2	0.9	5	83.0	4.6	6	84.3	3.6
	GAM	18	44.3	15.2	4	44.7	3.1	3	49.6	1.4	5	44.8	2.2	6	43.2	3.5
H ₂ (%)	FC	15	0.0		4	0.0		4	0.0		5	0.0		6	0.0	
	GAM	18	35.2	6.1	4	36.4	3.0	3	33.2	1.9	5	33.0	5.6	6	39.8	4.2
CO ₂ (%)	FC	14	15.2	5.5	4	14.3	3.3	4	12.8	5.6	5	15.4	9.0	6	11.6	3.2
	GAM	18	17.6	2.4	4	16.7	3.5	3	12.3	2.9	5	19.0	1.9	6	16.0	1.7
C ₂ H ₄ (%)	FC	14	0.0		4	0.0		4	0.0		5	0.0		6	0.0	
	GAM	18	0.7	0.1	4	0.6	0.2	3	0.5	0.1	5	0.7	0.1	6	0.8	0.1
(C ₂ H ₄) (%)	FC	14	0.0		4	0.0		4	0.0		5	0.0		6	0.0	
	GAM	14	0.0		4	0.1 ^a		3	0.0		5	0.0		6	0.0	

^a Traces of CO were found in 3 of the 4 cans in the 3-month withdrawal.
^b sig. 99% level in the overall.

Table 7 Summary of sensory intensity scores^a of enzyme-inactivated beef

Time in storage

Sensory Charac.	Grp	Initial			3 Month			6 Month			9 Month			12 Month			15 Month			Overall		
		n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd	n	Avg	sd
Discoloration	FC 16	16	1.7	0.4	8	2.1	0.6	4	1.7	0.4	5	1.8	0.4	5	2.0	0.5	5	1.8	0.5	43	1.8 ^b	0.5
	TP 19	19	2.3	0.6	9	2.7	0.7	4	2.5	0.5	5	2.6	0.6	5	2.9	0.5	5	2.4	0.9	47	2.5	0.6
	GAM 16	16	2.3	0.4	8	2.7	0.4	4	2.5	0.4	5	2.7	0.9	5	3.1	0.4	5	2.9	0.4	43	2.6	0.5
	ELE 17	17	2.1	0.4	8	2.6	0.5	3	3.1	0.5	5	2.5	0.7	5	3.0	0.4	5	3.1	0.5	43	2.6	0.6
Off-odor	FC 16	16	1.4	0.4	8	1.7	0.6	4	1.4	0.1	5	1.4	0.3	5	2.1	0.3	5	1.4	0.3	43	1.6 ^b	0.4
	TP 19	19	1.5	0.4	9	1.8	0.3	4	1.9	0.3	5	1.7	0.4	5	2.2	0.2	5	1.8	0.5	47	1.7 ^b	0.4
	GAM 16	16	2.4	0.4	8	2.4	0.4	4	2.8	0.1	5	2.6	0.8	5	2.9	0.8	5	2.6	0.4	43	2.5	0.5
	ELE 17	17	2.2	0.4	8	2.2	0.5	3	2.5	0.4	5	2.4	0.6	5	3.2	0.6	5	2.5	0.4	43	2.4	0.5
Irrad. Flavor	FC 16	16	1.3	0.6	8	1.2	0.4	4	1.2	0.2	5	1.3	0.4	5	1.3	0.2	5	1.1	0.1	43	1.3 ^b	0.4
	TP 19	19	1.2	0.3	9	1.2	0.2	4	1.2	0.1	5	1.1	0.1	5	1.4	0.4	5	1.2	0.3	47	1.2 ^b	0.3
	GAM 16	16	2.3	0.8	8	2.9	0.4	4	2.9	0.2	5	2.8	0.5	5	3.0	1.0	5	2.7	0.6	45	2.5	0.7
	ELE 17	17	2.3	0.6	8	2.6	0.5	3	2.6	0.5	5	2.5	0.3	5	2.6	0.6	5	2.4	0.4	43	2.4	0.5
Off-Flavor	FC 16	16	1.8	0.3	8	1.9	0.6	4	1.9	0.2	5	2.1	0.7	5	2.7	0.7	5	1.8	0.3	43	2.0	0.5
	TP 19	19	2.1	0.4	9	2.4	0.3	4	2.4	0.3	5	2.2	0.6	5	2.6	0.6	5	2.1	0.7	47	2.2	0.5
	GAM 16	16	2.0	0.4	8	2.2	0.3	4	2.2	0.3	5	2.2	0.6	5	2.2	0.7	5	2.3	0.4	43	2.2	0.4
	ELE 17	17	2.0	0.3	8	2.1	0.4	3	2.1	0.4	5	2.1	0.2	5	2.8	1.0	5	2.1	0.4	43	2.2	0.5
Mushiness	FC 16	16	1.6	0.6	8	1.5	0.3	4	1.5	0.4	5	1.7	0.3	5	1.7	0.6	5	2.1	0.9	43	1.6 ^b	0.6
	TP 19	19	2.8	0.6	9	3.1	0.5	4	3.1	0.7	5	3.1	0.6	5	3.9	0.3	5	2.9	0.6	47	3.0	0.6
	GAM 16	16	2.1	0.3	8	2.7	0.7	4	2.7	0.3	5	3.1	0.6	5	3.1	0.9	5	2.9	0.4	43	2.6	0.6
	ELE 17	17	2.4	0.4	8	2.6	0.5	3	2.6	0.3	5	2.8	0.8	5	3.2	0.7	5	2.3	0.3	43	2.6	0.6
Friability	FC 16	16	1.5	0.4	8	2.0	0.5	4	1.9	0.4	5	2.2	0.8	5	2.2	0.8	5	2.4	1.0	43	1.9 ^b	0.6
	TP 19	19	4.0	0.6	9	3.5	0.7	4	4.0	0.7	5	4.1	0.5	5	4.1	0.5	5	4.0	0.9	47	3.9 ^b	0.6
	GAM 16	16	2.4	0.4	8	3.2	0.4	4	3.4	0.8	5	3.5	0.5	5	3.5	0.5	5	3.4	0.5	43	2.9	0.7
	ELE 17	17	2.7	0.5	8	2.9	0.1	3	3.1	0.6	5	3.2	0.4	5	3.2	0.4	5	3.2	0.5	43	2.9	0.6

a. 9-point intensity scale: 1=none, 9=extreme

b. sig: 9% level in overall



Table 8 Summary of preference scores^a by technical and consumer panel of enzyme-inactivated beef.

Time in storage																	
Group	Initial		3 Month		6 Month		9 Month		12 Month		15 Month		Overall				
	n	Avg sd	n	Avg sd	n	Avg sd	n	Avg sd	n	Avg sd	n	Avg sd	n	Avg sd			
Technical Panel																	
16	6.5	0.5	8	6.4	0.6	4	6.8	0.2	5	6.4	0.6	5	6.1	0.5	43	6.4 ^b	0.5
19	5.9	0.4	9	5.6	0.4	4	5.6	0.1	5	6.9	0.6	5	5.8	0.3	47	5.8	0.4
16	5.5	0.5	8	5.5	0.4	4	5.4	0.4	5	5.1	0.6	5	5.1	0.8	43	5.4	0.6
17	5.6	0.5	8	5.6	0.4	3	5.4	0.2	5	5.3	0.7	5	5.1	0.4	43	5.4	0.5
Consumer Panel																	
15	5.6	0.6	8	6.1	0.4	5	6.2	0.5	5	5.9	0.6	5	6.1	0.5	43	5.9 ^b	0.6
18	6.6	0.3	9	6.5	0.3	5	6.4	0.3	5	6.6	0.3	5	6.4	0.3	47	6.4 ^b	0.4
15	5.9	0.5	8	5.8	0.5	5	5.6	0.2	5	5.5	0.8	5	5.6	0.5	43	5.7	0.6
16	6.0	0.5	8	5.6	0.2	4	5.5	0.5	5	5.5	0.7	5	5.5	0.4	43	5.6	0.5

^a 9-point hedonic scale: 1=dislike extremely, 9 like extremely.
 Sig. 95% level in overall.



Figure 1. Form used for determining sensory characteristics

N/ F/							MEATS <input type="checkbox"/> Beef <input type="checkbox"/> Pork <input type="checkbox"/> Ham <input type="checkbox"/> Other: _____		POULTRY <input type="checkbox"/> Chicken <input type="checkbox"/> Turkey <input type="checkbox"/> _____		MARINE PRODUCTS <input type="checkbox"/> Shrimp <input type="checkbox"/> Fish: <input type="checkbox"/> Other: _____	
D/ /												
SE	<input type="checkbox"/> COLD <input type="checkbox"/> WARM											
Ci: _____ In sample numerical score from 1 to 9:	<div style="text-align: center;"> <p><u>INTENSITY SCALE</u></p> <div style="display: flex; justify-content: space-between;"> <div> 1. None 2. Trace 3. Slight 4. Below moderate 5. Moderate </div> <div> 6. Above moderate 7. Strong 8. Very strong 9. Extreme </div> </div> </div>											
Sample Number	I N T E N S I T Y						C O M M E N T S					
	Discoloration	Off-Odor	Irradiation Flavor	Off-Flavor *	Mushiness	Friability						

Code No. _____



Fig. 2. Form used for preference evaluations

PREFERENCE		
LIKE EXTREMELY	9	
LIKE VERY MUCH	8	
LIKE MODERATELY	7	
LIKE SLIGHTLY	6	
NEITHER LIKE NOR DISLIKE	5	
DISLIKE SLIGHTLY	4	
DISLIKE MODERATELY	3	
DISLIKE VERY MUCH	2	
DISLIKE EXTREMELY	1	

COMMENTS:



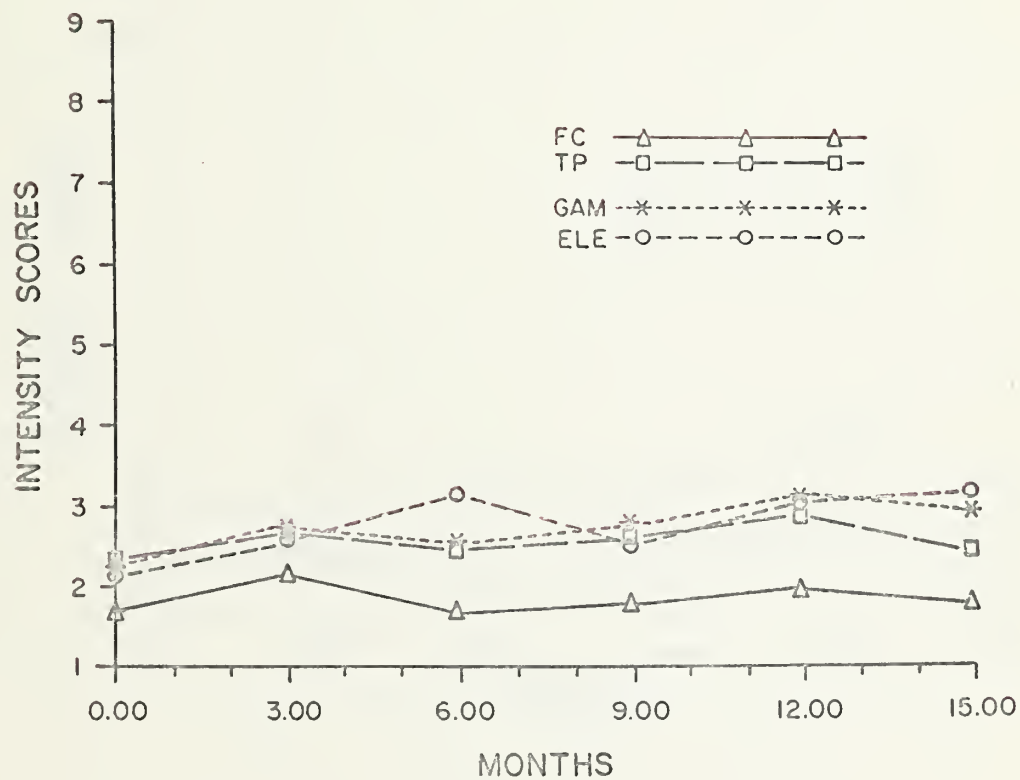


Figure 3 - Effect of processing and storage on discoloration of enzyme-inactivated beef: Technological panel, n=8.



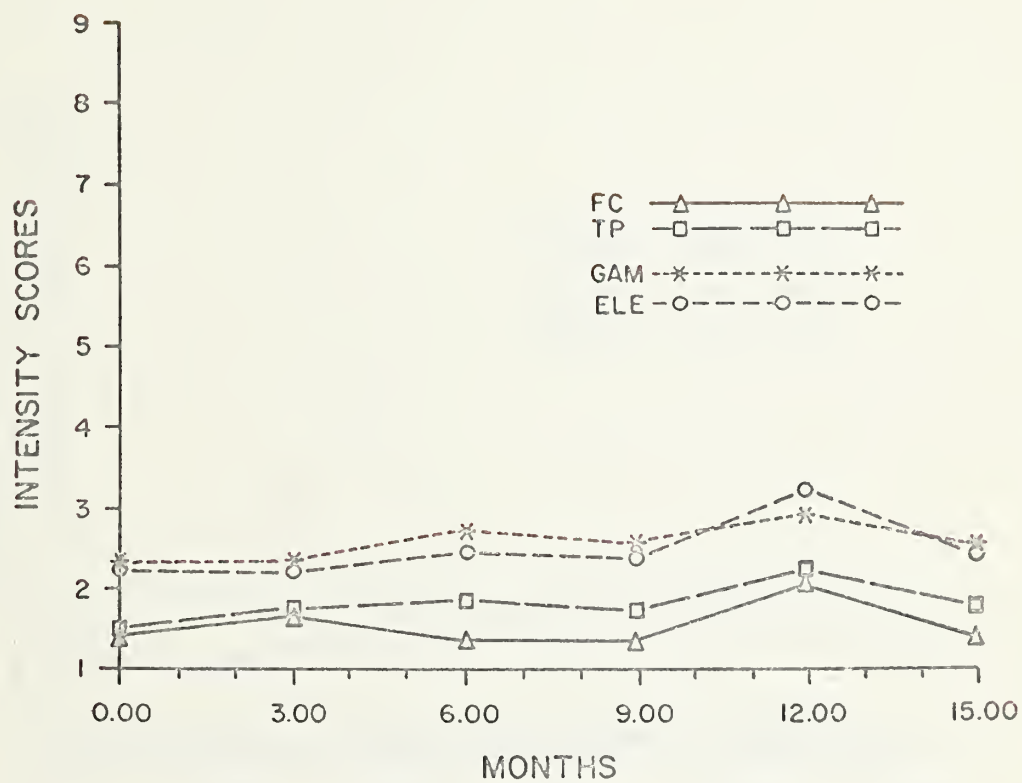


Figure 4 - Effect of processing and storage on off-odor of enzyme-inactivated beef: Technological panel, n=8.



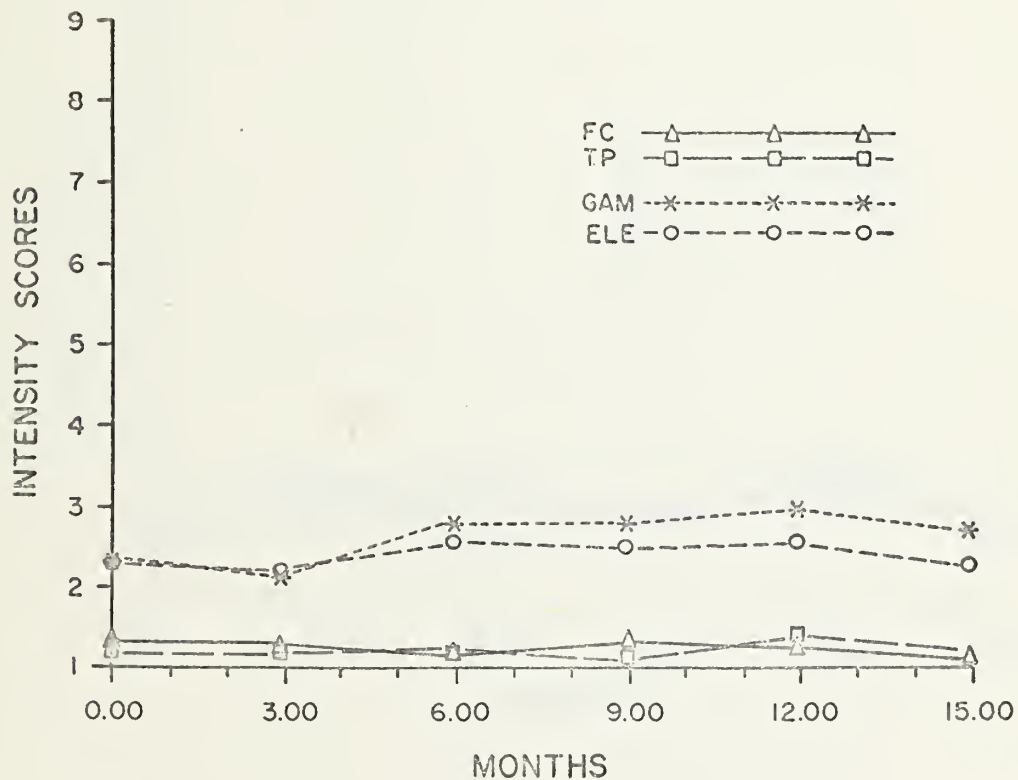


Figure 5 - Effect of processing and storage on irradiation flavor of enzyme-inactivated beef: Technological panel, n=8.



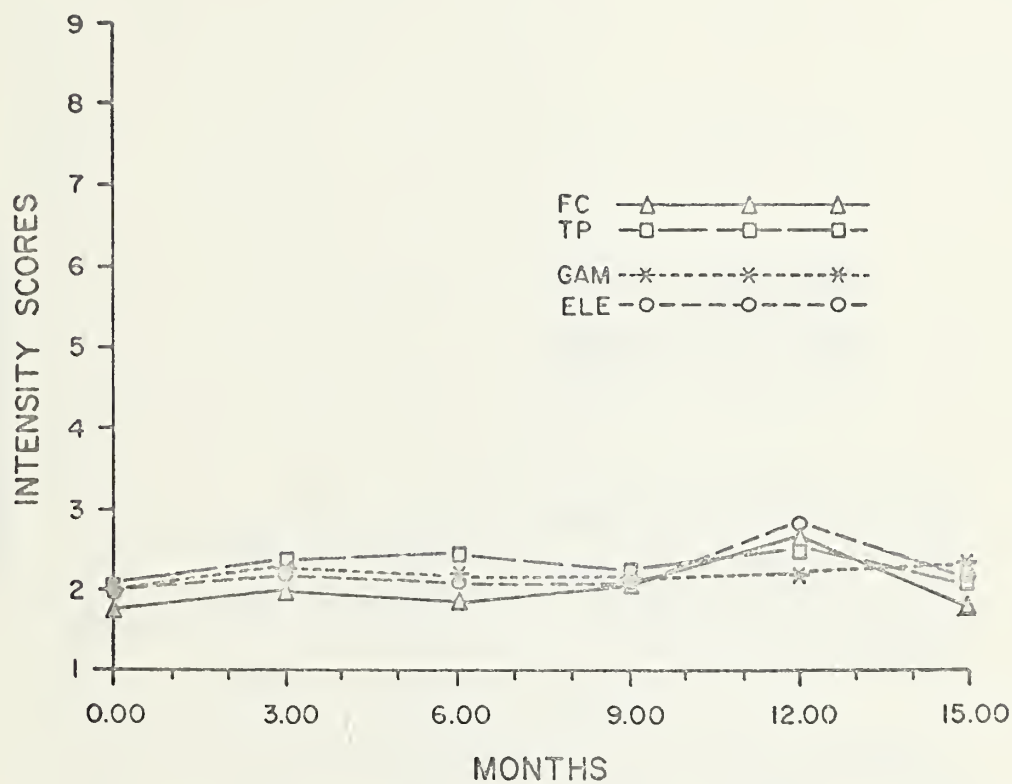


Figure 6 - Effect of processing and storage on off-flavor (other than irradiation flavor) of enzyme-inactivated beef: Technological panel, n=8.



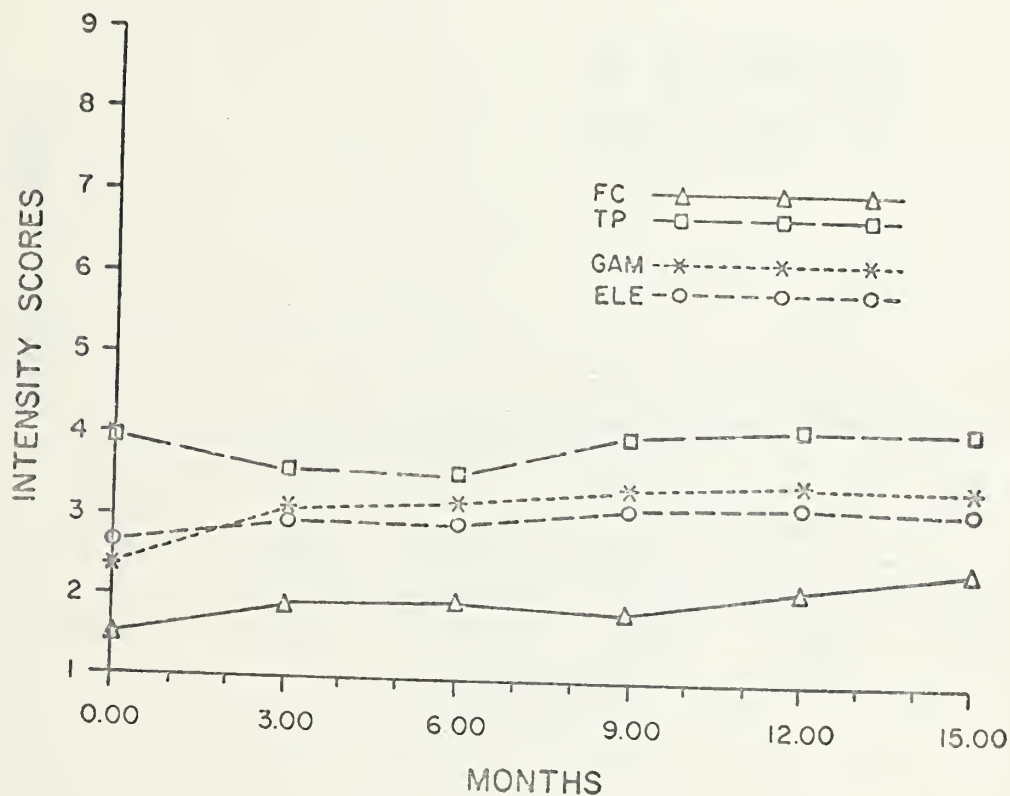


Figure 7 - Effect of processing and storage on friability of enzyme-inactivated beef: Technological panel, n=8.



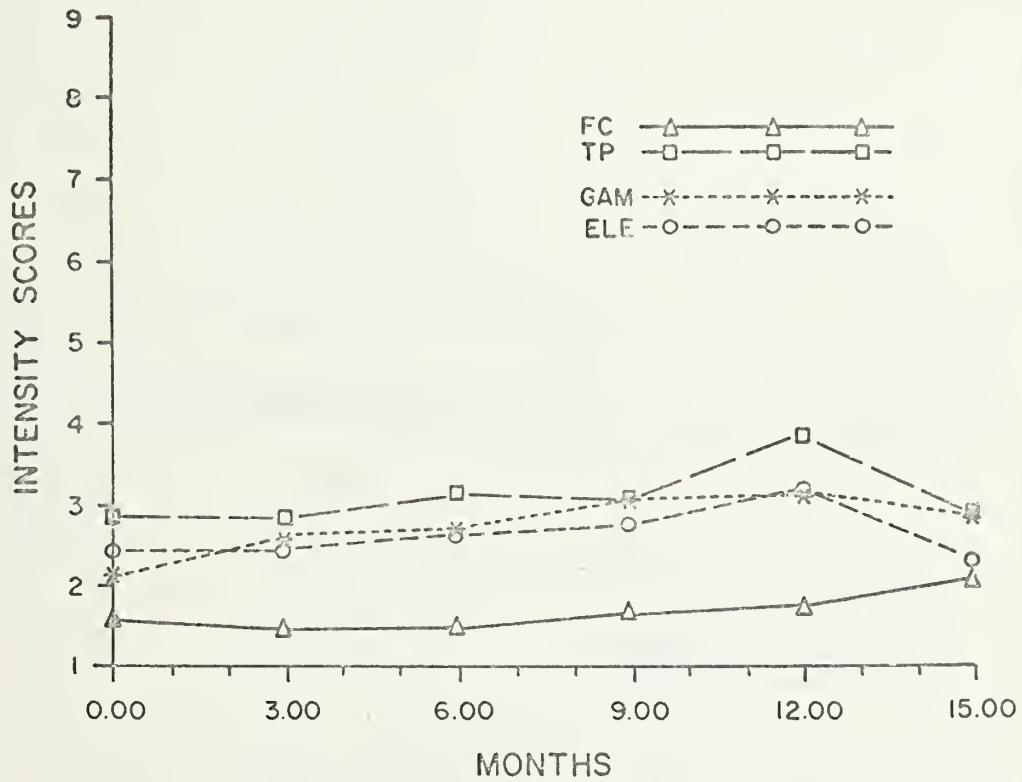


Figure 8 - Effect of processing and storage on mushiness of enzyme-inactivated beef: Technological panel, n=8.



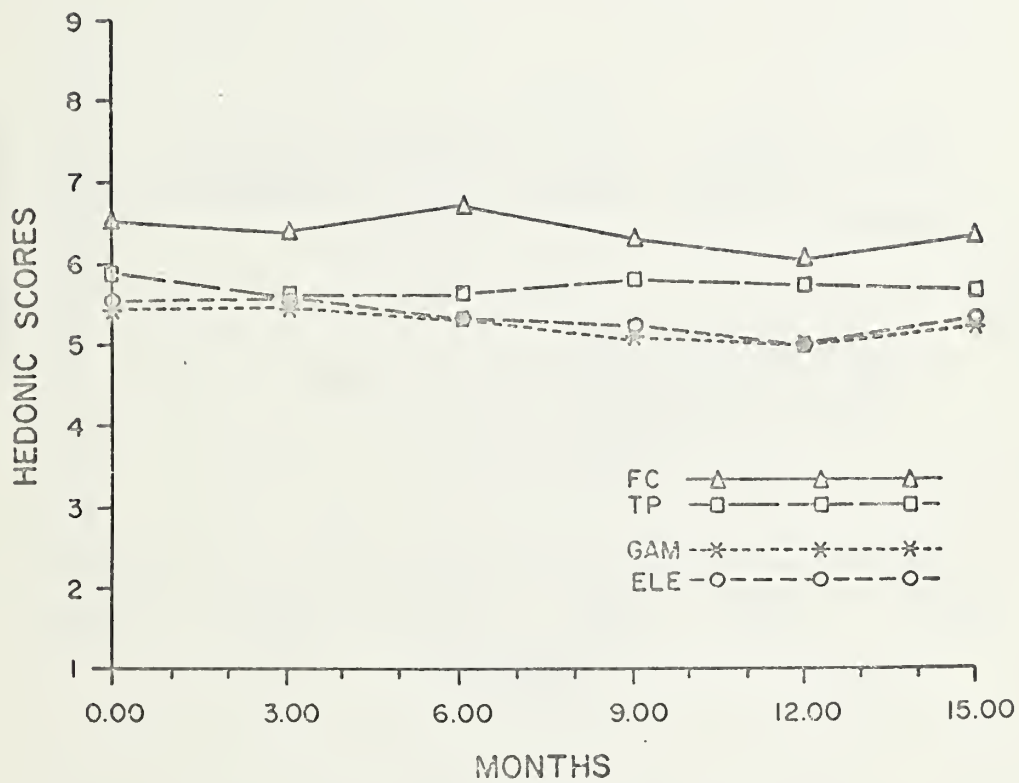


Figure 9 - Effect of processing and storage on hedonic preference of enzyme-inactivated beef: Technological panel, n=8.



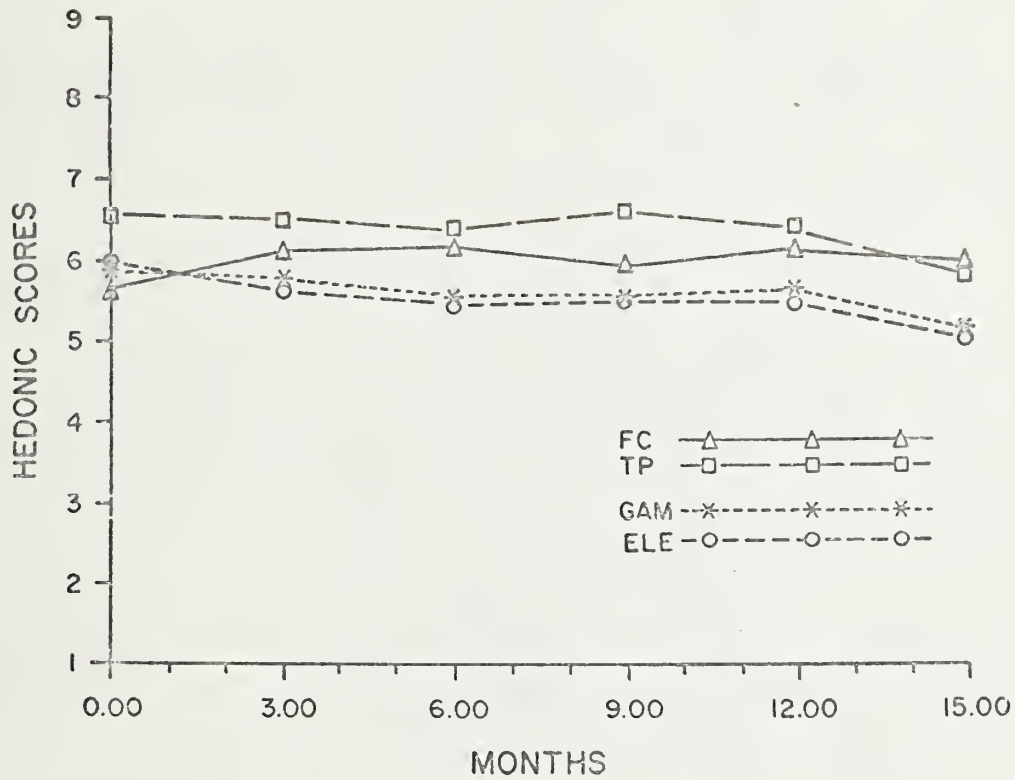


Figure 10 - Effect of processing and storage on hedonic preference of enzyme-inactivated beef: Consumer panel, n=32.



